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The Target Indicator Experiment on TacSat-2

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Introduction: The Navy's Target Indicator Experiment (TIE) payload is part of the Air Force Research Laboratory (AFRL)-developed TacSat-2 spacecraft, which is the second in a series of Operationally Responsive Space (ORS) satellites built to experiment with making space-based assets more responsive to the needs of tactical forces. TacSat-2 was launched on 16 December 2006 from NASA's Wallops Flight Facility on a Minotaur 1 launch vehicle. The spacecraft was placed into a 420 km orbit at an inclination of 40 degrees. The NRL TIE payload is designed to perform real-time collection of RF signals from 0.5 to 18.0 GHz using an adaptation of an unmanned air vehicle payload. The TIE payload is also capable of collecting the Automatic Identification System (AIS) signal now required on large ships for maritime safety and security.

Payload Development: Our sponsors at the Office of Naval Research, DoD Office of Force Transformation, the DoD Advanced Concept Technology Demonstration (ACTD) process, and the Air Force Space Test Program accepted a higher level of risk than is found in the typical spacecraft payload development program, and encouraged the use of novel approaches to hardware and software development. On the hardware side, this allowed the NRL team to use non-radiation-hardened commercial off-the-shelf (COTS) and government off-the-shelf (GOTS) hardware. The TIE payload contains numerous field programmable gate arrays, random access memory, and processors that are considered soft and subject to single event upset. While TacSat-2 is in a relatively benign orbit from a radiation standpoint, the TIE payload has not experienced any reboots or data corruptions that were radiation induced. On the software side, our sponsor's approach allowed us to use the network-connected, LINUX-based computers that are at the heart of the TIE payload. Because of this LINUX implementation, considerable capability exists for both adapting and reprogramming the payload to accommodate on-orbit anomalies, new experimentation possibilities, and evolving requirements. In addition, the AIS receiver system was implemented as a software-reconfigurable radio to optimize its performance and flexibility. This makes it possible to upload new software to the radio to improve its performance.

Development of the TIE payload was conducted in parallel with that of the TacSat-2 spacecraft. In order to minimize integration issues late in the program, simulators were used to emulate the spacecraft, ensuring the payload's compliance with established Interface Control Documents. This resulted in a very efficient test and integration campaign when the TIE flight hardware was delivered to AFRL. The use of software industry standards, including TCP/IP and Ethernet, and space standards such as those of the Consultive Committee for Space Data Systems (CCSDS) reduced the need for custom software, and were critical to meeting the aggressive schedule and integration challenges.

AIS Background: AIS messages provide situational awareness for ships as they transit the oceans and move through busy harbors. These messages include information about the ship such as its name, heading and speed, size, and cargo. AIS transponders are required on many commercial vessels by international treaty, insurance requirements, and U.S. law. AIS signals are broadcast in the VHF marine band, and are primarily line-of-sight. From the mast of a ship, a radius of about 25 kilometers is a typical AIS reception area. From a low Earth orbiting spacecraft, AIS messages can be received over very significant footprints, almost 13.9 million square kilometers for the TIE payload. AIS messages are self-organizing time division multiple access (STDMA) messages. This critical design feature allows ground-based systems to self-deconflict messages. However, collection platforms that see beyond line-of-sight, such as a spacecraft, will see many self-organized networks of transponders, making this feature one source of interference. Additional sources of interference include other in-band and near-band licensed spectrum users. One method the TIE payload uses to mitigate these interference issues is to use a phased array antenna. The physical size of the array is important since at VHF frequencies it allows the beamforming electronics to create a beam with some amount of directivity and about 10 dB of gain.

On-Orbit Results: From the data that TIE has collected, it is apparent that the interference concerns are valid. We experience both co-channel interference caused by AIS transmitter density issues, and near-band interference caused by high-power radiations in adjacent bands of the receiver. The most disabling interference appears to be the near-band interference that is primarily continuous-wave in nature. When this high duty-cycle interference is present, the TIE AIS receiver performance drops to zero. This interference is the most likely source of our performance degradation over the United States, particularly the East coast, as shown in Fig. 6. Where many ships should be present,

none are detected. Other regions of the Earth where ship density is known to be very high, such as the South China Sea and Malacca Straits, do not experience a drop-off in performance, as shown in Fig. 7. In these figures, each ship icon represents a unique AIS message detected by the TIE payload.

Summary: With careful consideration of the orbital environment and the appropriate use of screening and testing, COTS and GOTS electronic components can be used successfully for higher-risk, short-duration space missions. Industry standard operating systems, scripting languages, and software protocols can be used to leverage commercial software developments to save time and money while producing a flexible spaceflight payload system that meets design requirements. The TIE payload successfully collects AIS messages from space, even in areas of high traffic density, supporting maritime safety and security. However, certain near-band transmissions present challenges to the collection of AIS messages from space.

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FIGURE 6
TIE AIS receiver performance degradation along the U.S. Eastern and Gulf coasts.

FIGURE 7
TIE AIS receiver performance in an area of high ship traffic density—South China Sea and Malacca Straits.